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EVALUATION OF WOVEN FABRICS BASED ON GRAFIL XAS 3000-FILAMENT CARBON FIBRE

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SUMMARY

A number of all-carbon and carbon/glass hybrid fabrics have been woven without difficulty from 3000-filament, Courtaulds XAS fibre. The fabric properties were measured.

Laminates were made from each fabric, using the Ciba-Geigy epoxide XD927 as the common matrix throughout. There were no problems with wetting or cure.

Mechanical tests showed the all-carbon five-shaft satin to be somewhat stronger than the twill while in the hybrid fabrics, the twill was stronger than the plain-weave.

Neither with the all-carbon fabrics or with the carbon/glass hybrids was there a marked effect of the weave on modulus.

In general, the level of mechanical properties showed woven XAS to be an extremely useful reinforcement, with good translation of fibre properties into laminates.

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1 INTRODUCTION

Attention has been drawn in previous investigations, to the very high strength and stiffness of Courtaulds Grafil XAS carbon fibre, sometimes known as 'Super A'[1]. It is widely used for sports goods and is finding increasing uses in Aerospace.

The fibre properties have been measured by Moreton[2].

Mechanical properties of laminates based on unwoven XAS pre-preg were determined by the authors who compared a novel hot-setting Friedel-Crafts matrix[3] with a standard hot-setting epoxide Shell DX210/$BF_3$400.

A more detailed statistical evaluation of the mechanical properties of the unwoven pre-preg system XAS/914 is nearing completion at British Aerospace, Manchester Division, Woodford[4].

In the present work, a number of XAS all-carbon and hybrid fabrics of different construction were woven and processed into high-pressure laminates, using an epoxy resin matrix.

Basic fabric properties as well as laminate mechanical properties were measured, in order to establish which constructions were the more efficient; and to indicate possible values for specification purposes.

During the course of this investigation Courtaulds changed their commercial XAS production to a somewhat finer filament - specifically from 1.5 denier to 1.22 denier precursor. It was therefore necessary to repeat some measurements in order to check that fabric and laminate properties were substantially unchanged.

2 MATERIALS

A number of fabrics were woven by Carr Reinforcements Limited on the rapier-loom. All constructions were based on sized and surface-treated XAS fibre containing 3000-filaments per tow.

In the all-carbon series there were unidirectional, twill-weave and five-shaft satin cloths. The last construction was woven twice, first of all in carbon produced from traditional 1.5 denier precursor and again, later, when the 1.22 denier precursor was introduced.

Hybrid cloths consisted of glass and carbon, the former being 300 tex E-glass and the latter comprising 3000-filament tow based on the 1.5 denier precursor.

The hybrid constructions were as follows:

(a) Unidirectional cloth with three warps of glass to each carbon warp. The warps were held together by a light glass weft, consisting of 44 tex E-glass fibre.

(b) Plain-weave, comprising three glass and one carbon tow, both warp and weft.

(c) Twill-weave, also made with three glass and one carbon tow, both warp and weft.

Detailed measurements for each construction are given in Table 1.

The matrix resin was the Ciba-Geigy two-part liquid epoxy XD927. The mixing ratio was 36 parts by weight of hardener to 100 parts of resin. In general, a wet laminating method was used, with the resin being hardened at a constant temperature a little above ambient, followed by post-cure at elevated temperatures.

The details are given below.

3 LAMINATING TECHNIQUES

All the laminates were prepared in an open-ended light alloy mould with an interior size of 300 mm x 150 mm.

The following procedure was followed for all the various cloths:-

The requisite number of layers was cut to size, there being eight for the bi-directional cloths and 13 layers for the unidirectional types.

A pool of XD927 epoxy resin mix was poured into the mould cavity, the mould having been previously coated with Vydax release agent. The first layer of fabric was placed in the resin and allowed to wet-out thoroughly before applying a further layer. In the case of the bi-directional fabrics, each layer was in addition, rolled with a paddle roller before applying the next layer. Once the lay-up was complete, the top of the mould was placed in position, and the assembly left for 2½ h at room temperature without any pressure being applied. This procedure is followed to allow the resin viscosity to increase prior to the application of pressure. The mould was then placed in a hydraulic press, the platens of which were maintained at 35°C, and a pressure of 1.3 MPa applied gradually. The mould was left overnight in the press before ejection of the moulding.

All the laminates were given a 3 h post-cure at 100°C in an air-circulating oven before testing. No difficulties were experienced with any of the fabrics in wetting or cure during the above programme.

4 TESTING PROCEDURES

The laminates moulded from the bi-directional fabrics were tested both in warp and weft directions; while the laminates based on the unidirectional fabric were tested in the longitudinal direction only.

The various test specimens were cut from the moulded sheets using a diamond-edged cutting wheel (152 mm diameter x 1.6 mm thickness), the grit size being 85-100.

The details of the various tests performed are given below:-

(i) Flexural strength

A standard specimen was used 100 mm x 10 mm x 2 mm, with a span of 80 mm, as described by Sturgeon[5], in the case of the all-carbon cloths. The width of the specimens was increased to 20 mm for the hybrid cloths in order to ensure that a sufficient number of repetitions of the glass/carbon pattern were achieved, so giving a representative cross-section.

The load was applied at a rate of 20 mm/min.

(ii) Interlaminar shear strength

A standard specimen 12 mm x 10 mm x 2mm, with a span of 10 mm, as described by Dootson[6], was used for all fabrics.

The load was applied at a rate of 2 mm/min.

(iii) Tensile modulus

A parallel-sided specimen 150 mm x 10 mm x 2 mm was used. Light alloy end-pieces were bonded to the ends of each specimen with Redux 410 epoxy adhesive.

The specimen was loaded at a rate of 2 mm/min to about 50% of the expected failing load and the strain measured with an Instron strain gauge extensometer.

This test was performed only on the all-carbon specimens as no suitable extensometer was available for specimens wider than 10 mm.

(iv) Flexural modulus

This test was performed on the hybrid laminates as an alternative to measuring tensile modulus. The specimen size was 220 mm x 20 mm x 2 mm and the rate of loading was 10 mm/min.

(v) Tensile strength

In the case of the all-carbon laminates, once the tensile modulus had been obtained, each specimen was re-loaded at a rate of 2 mm/min until failure occurred. Specimens for the hybrid materials were similar except that the width was increased to 20 mm, as explained above.

All the various tests were performed on a floor-mounted Instron machine (type 115). In general, ten replicate specimens were used for each type of test.

The volume fraction of fibre was determined for each laminate using the burn-off technique[7].

5 RESULTS

5.1 All-carbon cloth

The detailed results of the various mechanical tests are given in Table 2. In order to make easier comparisons between the different fabrics, the mean values reported have been corrected in proportion, to a fibre volume fraction of 60% (actual volume fractions varied between 55% and 65%).

Laminates made from the two bi-directional fabrics gave excellent mechanical properties in both warp and weft directions. The tensile and flexural strengths of the satin-weave based laminates were somewhat higher than those made from the twill-weave fabric. The higher strengths achieved are not surprising because the fibres run straighter (less crimp) in a satin-weave cloth than those in a twill-weave. There appears, however, to be very little difference in the moduli of laminates made from the two cloths.

The laminates based on unidirectional fabric also gave fairly good results, although the flexural and tensile strengths are a little disappointing. Comparing these tensile strengths with those from earlier work where unwoven XAS fibre was used[1], the strength was about 1500 MPa unwoven as compared with 1200 MPa for the woven material at the same volume fraction.

5.2 New denier fibres

The laminates made from the satin-weave fabric, which was woven from the new, lower denier, carbon fibre, were tested in exactly the same way as the others. The results are given in Table 3 alongside the values obtained for the previous denier satin-weave fabric for comparison. It can be seen that there appears to be no significant difference between the two fabrics and it may reasonably be assumed that a similar result would have been obtained if either twill or unidirectional cloth had been used.

5.3 Hybrid fabrics

The unidirectional 3:1 glass/carbon hybrid laminates gave very good mechanical properties with values very close to those reported in earlier work using a 5000-filament cloth[8].

As was found with the bi-directional carbon cloths, the hybrid cloth in which the fibres lie straightest gave the better strength; in this case the twill-weave giving higher values than the plain-weave. A notable feature of the twill-weave laminates was their balanced nature, the mechanical properties being very similar in both warp and weft directions.

The full results for the hybrid fabrics can be found in Table 4.

6 CONCLUSIONS

All of the fabrics made from the XAS 3000-filament fibre, whether all-carbon or hybrid, were woven successfully to a good commercial quality using the high-speed rapier-loom.

Mechanical tests on the derived epoxy-bonded laminates showed the five-shaft all-carbon material was stronger than the corresponding twill, presumably because of the lower crimp, though there was little change in modulus.

Although the satin-weave drapes nicely, the drawback is that it frays easily when cut; and special care must therefore be taken to bind the edges before tailoring.

In the hybrid constructions, the plain-weave proved easy to handle without deformation and there was little tendency to fray. The twill frays more readily, has a softer handle and gives a somewhat higher strength than the plain. Again, there was little difference in modulus between the laminates derived from the two weaves.

The tensile and flexural strengths of laminates made from the unidirectional carbon fibre cloth were satisfactory but a little lower than expected as compared with specimens made from unwoven pre-preg. This may have been due to the presence of the light glass weft; and further experiments on the possible effect of alternative weft materials are in hand.

Previous mechanical tests which compared laminates made from unwoven pre-preg had shown XAS fibre as giving values only slightly below those from Type II fibre[1]. This general conclusion has been confirmed, for woven XAS reinforcement, in the present programme.

It is hoped that the values found here for both fabrics and derived laminates will be useful in the drafting of appropriate MOD specifications for woven cloth.

Acknowledgments

Textiles Section, Materials Department were responsible for the direct measurement of fabric properties. Miss T. Lynch assisted in the greater part of laminate preparation.

Table 1

PHYSICAL PROPERTIES OF HYBRID AND ALL-CARBON FABRICS BASED ON 3000-FILAMENT XAS CARBON FIBRE

Fabric type	Yarn count yarns/cm			Nominal thickness under a pressure of 0.5 N/cm^2	
	Warpway	Weftway	Mass g/m^2	mm	in
Unidirectional hybrid, weaving ratio, 3 glass/1 carbon light glass weft	6.67	3.90	207	0.29	0.011
Plain-weave hybrid, weaving ratio, 3 glass/1 carbon	6.67	6.20	353	0.37	0.015
2 x 2 twill-weave hybrid, weaving ratio, 3 glass/1 carbon	6.67	6.35	392	0.46	0.018
Unidirectional, carbon warp, light glass weft	6.72	4.00	176	0.25	0.010
2 x 2 twill-weave, all-carbon	6.67	6.25	309	0.44	0.017
Five-shaft satin-weave, all-carbon	6.72	6.06	297	0.48	0.019
Five-shaft satin-weave, all-carbon (new denier)	6.71	6.29	280	0.42	0.017

Table 2

MECHANICAL PROPERTIES OF LAMINATES FROM XD927 EPOXY/XAS 3000-FILAMENT FIBRE

Fabric construction and direction of test	Flexural* strength MPa	Tensile* strength MPa	Tensile* modulus GPa	Interlaminar shear strength MPa
Five-shaft satin, warp direction	Mean = 1020 C.V. = 7.5%	Mean = 791 C.V. = 4.8%	Mean = 84 C.V. = 2.8%	Mean = 58 C.V. = 3.8%
Five-shaft satin, weft direction	Mean = 1005 C.V. = 10.8%	Mean = 822 C.V. = 4.4%	Mean = 72 C.V. = 4.3%	Mean = 58 C.V. = 3.4%
2 x 2 twill, warp direction	Mean = 882 C.V. = 12.2%	Mean = 630 C.V. = 10.4%	Mean = 74 C.V. = 5.6%	Mean = 57 C.V. = 5.4%
2 x 2 twill, weft direction	Mean = 912 C.V. = 7.8%	Mean = 678 C.V. = 5.7%	Mean = 73 C.V. = 4.1%	Mean = 60 C.V. = 3.3%
Unidirectional	Mean = 1381 C.V. = 6.8%	Mean = 1203 C.V. = 9.3%	Mean = 131 C.V. = 5.0%	Mean = 72 C.V. = 4.9%

* Values corrected to 60% V_f

Table 3

COMPARISON OF THE MECHANICAL PROPERTIES OF LAMINATES MADE FROM FIVE-SHAFT SATIN FABRIC BASED ON THE NEW AND OLD DENIER XAS 3000-FILAMENT CARBON FIBRE

Denier and direction of test	Flexural* strength MPa	Tensile* strength MPa	Tensile* modulus GPa	Interlaminar shear strength MPa
New, warp direction	Mean = 1160 C.V. = 4.2%	Mean = 895 C.V. = 6.4%	Mean = 73 C.V. = 4.4%	Mean = 61 C.V. = 1.2%
Old, warp direction	Mean = 1020 C.V. = 7.5%	Mean = 791 C.V. = 4.8%	Mean = 84 C.V. = 2.8%	Mean = 58 C.V. = 3.8%
New, weft direction	Mean = 1168 C.V. = 3.7%	Mean = 830 C.V. = 7.2%	Mean = 74 C.V. = 9.1%	Mean = 62 C.V. = 5.2%
Old, weft direction	Mean = 1005 C.V. = 10.8%	Mean = 822 C.V. = 4.4%	Mean = 72 C.V. = 4.3%	Mean = 58 C.V. = 3.4%

* Values corrected to 60% V_f

Table 4

MECHANICAL PROPERTIES OF LAMINATES MADE FROM 3:1 GLASS/CARBON HYBRID CLOTHS

Fabric construction and direction of test	Flexural strength MPa	Tensile strength MPa	Flexural modulus GPa	Interlaminar shear strength MPa	Volume fraction glass and carbon
Unidirectional	Mean = 919 C.V. = 4.8%	Mean = 680 C.V. = 7.0%	Mean = 54 C.V. = 4.5%	Mean = 56 C.V. = 1.7%	$V_{fg} = 0.45$ $V_{fc} = 0.15$
2 x 2 twill, warp direction	Mean = 507 C.V. = 5.8%	Mean = 442 C.V. = 6.4%	Mean = 48 C.V. = 2.8%	Mean = 39 C.V. = 4.8%	$V_{fg} = 0.51$ $V_{fc} = 0.15$
2 x 2 twill, weft direction	Mean = 507 C.V. = 5.8%	Mean = 470 C.V. = 2.9%	Mean = 48 C.V. = 4.3%	Mean = 46 C.V. = 8.8%	$V_{fg} = 0.51$ $V_{fc} = 0.15$
Plain-weave, warp direction	Mean = 424 C.V. = 7.8%	Mean = 425 C.V. = 3.4%	Mean = 47 C.V. = 1.1%	Mean = 42 C.V. = 3.4%	$V_{fg} = 0.52$ $V_{fc} = 0.20$
Plain-weave, weft direction	Mean = 349 C.V. = 6.5%	Mean = 361 C.V. = 5.9%	Mean = 44 C.V. = 5.2%	Mean = 38 C.V. = 4.5%	$V_{fg} = 0.49$ $V_{fc} = 0.18$

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17. Abstract

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